Patterns of Injuries to Front-Seat Occupants of Airbag Equipped Vehicles in Frontal Crashes

CIREN Public Meeting
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Harborview Medical Center
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Agenda

- Examine injury patterns under variety of restraint conditions
  - Brief history
  - Definitions & Terminology
  - Demonstrate some of the unique benefits of the CIREN project

History

1975 Belt Availability Rate: ~50%

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History

1975 Belt Use Rate: 5.6%

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History

1975 Injury Rate: 185 per 100 Million Vehicle Miles Traveled (VMT)

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History

1975 Fatality Rate : 2.5 per 100 Million Vehicle Miles Traveled (VMT)

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History
2000 vs. 1975 Statistics

- Belt Availability Rate: 99.9% vs ~50%
- Belt Use Rate: 55.5% vs 5.6%
- Injury Rate: 130 vs 185 per 100M VMT
- Fatality Rate: 1.5 vs 2.5 per 100M VMT

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Definitions & Terminology

SOURCE

versus

MECHANISM

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Sources of Injury

1) Objects contacted by the body

   knee bolsters, steering wheels, A-pillars, windshields, seatbelts, other vehicle, ground

2) Energy that causes injury

   crash energy, airbag inflation energy, belt tensioner energy

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Mechanism of Injury

- The specific mechanical action that produces the injury
  - tissue level (tension, compression, shear)
  - organ level (bending, axial compression, flexion)
  - body-region level (compression, acceleration, rate of loading)

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Mechanism of Injury

- Can only be determined through controlled laboratory testing

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Key Factors Influencing Injury Risk

- Crash Severity (ΔV/EBS)
- Seatbelt Usage
- Age

Keep these points in mind when reviewing the following case examples

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Stating the Obvious

- The elderly have lower tolerance to crash severity than the young adult even under optimal restraint conditions
- Young adults have higher tolerance to crash severity than the elderly even under minimal restraint conditions

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Changing Patterns of Injury in Frontal Crashes by Restraint Conditions

- Seatbelts Only
  - case examples
- Airbags Only
  - case examples
- Seatbelts with Airbags
  - case examples

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Patterns of Injury in Frontal Crashes

- **With seatbelt only**
  - Head/face injuries can occur from steering-wheel contact in severe crashes

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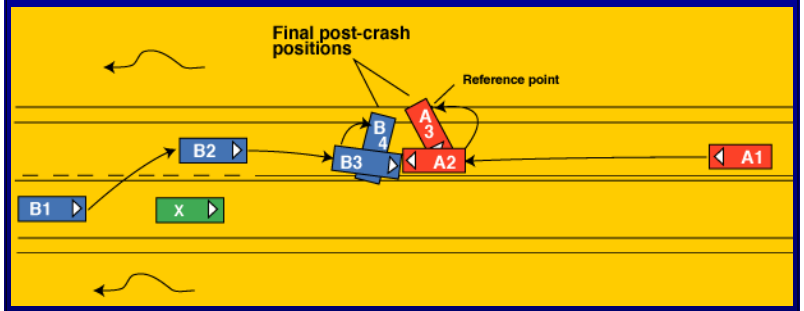

Case Vehicle (A): 1993 Jeep Cherokee (in red)
Vehicle (B): 1994 Ford Probe
Vehicle (B) passes on a double-yellow line and struck case vehicle headon
Dark, clear, dry asphalt roadway

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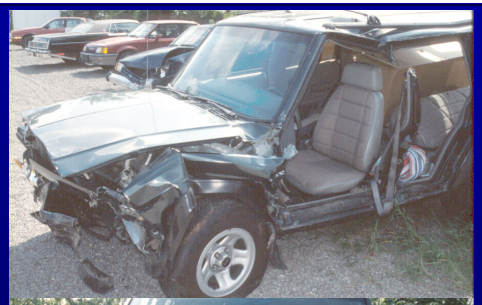

28-mph ΔV

CDC = 12-FDEW-3

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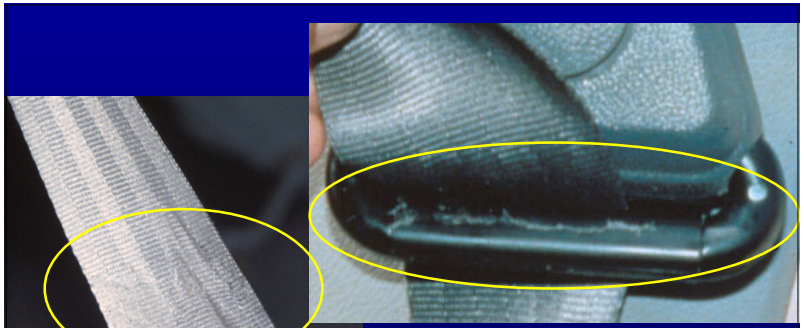

Witness marks indicating belt use

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Severe steering-wheel rim deformation

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Medical images, injury photographs and diagrams removed

- **45 year-old male driver; 6’ 0”; 205 lb**
- **3-point belt worn, no airbag available**
- **AIS-2 facial fractures from head contact with SW**
- **AIS-2 lower extremity fracture present**

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Patterns of Injury in Frontal Crashes

- **With seatbelt only**
  - Head/face injuries from steering-wheel contact in severe crashes
  - Thoracic/abdominal injuries likely in severe crashes

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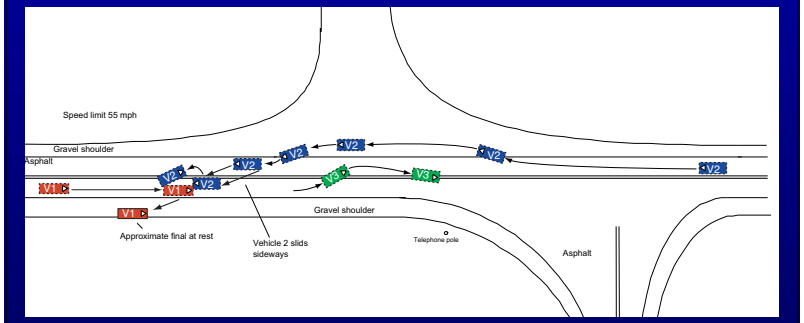

Case Vehicle (A): 1994 Ford Ranger Supercab pickup (in red)

Vehicle (B): 1995 Ford Mustang

V3 attempts left-turn, V2 takes avoidance, loses control, crosses a double-yellow line and struck case vehicle headon

Daylight, clear, dry asphalt roadway

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25-mph + ΔV

CDC = 12-FYEW-3

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Latch found in receiver

Load marks on continuous loop

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Medical images, injury photographs and diagrams removed

- 53 year-old female driver; 5’ 10”; 180 lb
- 3-point belt worn, no airbag available
- AIS-4 head/brain injuries from steering-wheel contact
- AIS-4 chest and AIS-3 abdomen injuries from belt loading
- AIS-3 pelvic and AIS-2 lower extremity fractures also occur

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Patterns of Injury in Frontal Crashes

- **With seatbelt only**
  - Head/face injuries from steering-wheel contact in severe crashes
  - Thoracic/abdominal injuries likely in severe crashes
  - **Abdominal organ injuries can be caused by shoulder-belt loading, especially when used without a lap belt**

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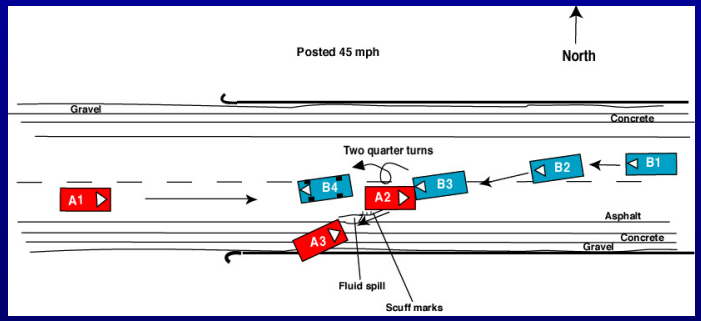

Case Vehicle (A): 1993 Ford Escort, 4-door hatchback (in red)

Vehicle (B): 1986 Chevrolet Camaro

V2 loses control, crosses centerline line and strikes case vehicle headon

Daylight, snow, icy asphalt roadway

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28-mph ΔV

CDC = 12-FYEW-4

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Both front seat occupants using 2-point automatic shoulder belt without the manual lap belt

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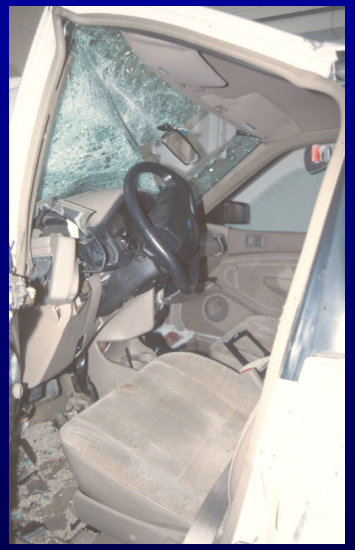

Severe SW rim deformation

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Medical images, injury photographs and diagrams removed

- 20 year-old male driver; 6’ 0”; 182 lb
- 2-point automatic shoulder belt worn, no airbag available
- AIS-2 abdominal (visceral) injury from belt loading
- AIS-3 lower extremity fracture from knee contact with knee bolster (axial load)

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Medical images, injury photographs and diagrams removed

- 20 year-old male RF passenger; 6’ 3”; 160 lb
- 2-point automatic shoulder belt worn, no airbag available
- AIS-5 and AIS-2 abdominal (visceral) injuries from belt loading
- AIS-2 brain injury from head contact with instrument panel

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Patterns of Injury in Frontal Crashes

- With only airbag (in-line crashes)
  - Head, face, and thorax are fairly well protected by the airbag system
  - Upper and lower extremity injuries still common

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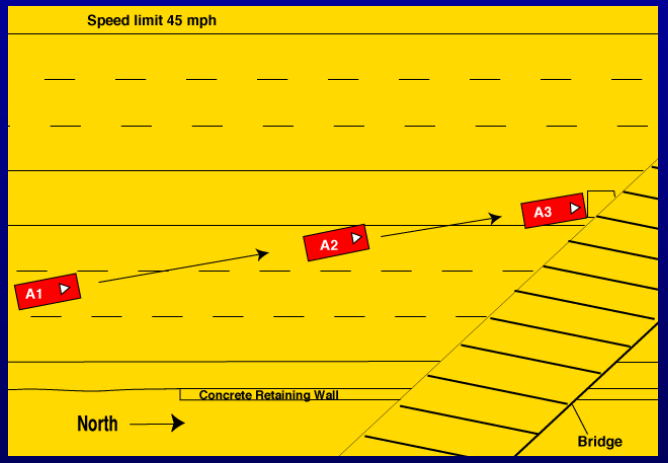

Case Vehicle (A): 2000 Buick Regal (in red)
Driver accelerated into median, then a bridge support
Daylight, cloudy, dry asphalt roadway

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CDC: 12-FDEW-5

PDOF: 360 degrees

160 cm of direct damage

108 cm of maximum crush

Impact Severity (mph):

total	60
longitudinal	- 60
lateral	- 0

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2G4WF5515Y1	System Status At Deployment
SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Passenger Front Air Bag Suppression Switch Circuit Status	Air Bag Not Suppressed
Ignition Cycles At Deployment	665
Time Between Near Deployment And Deployment Events (sec)	N/A

Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Adjusted Algorithm Velocity Change	-1.76	-3.95	-10.09	-14.92	-22.38	-32.03	-42.12	-47.83	-51.34	-53.53	-54.85	N/A	N/A	N/A	N/A

PRE-CRASH DATA			Electronic Data Validity Check Status = VALID	
Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle	Brake Switch Circuit Status
-5	48	1856	16	OFF
-4	51	2048	29	OFF
-3	54	2752	33	OFF
-2	58	3904	100	OFF
-1	60	4032	100	OFF

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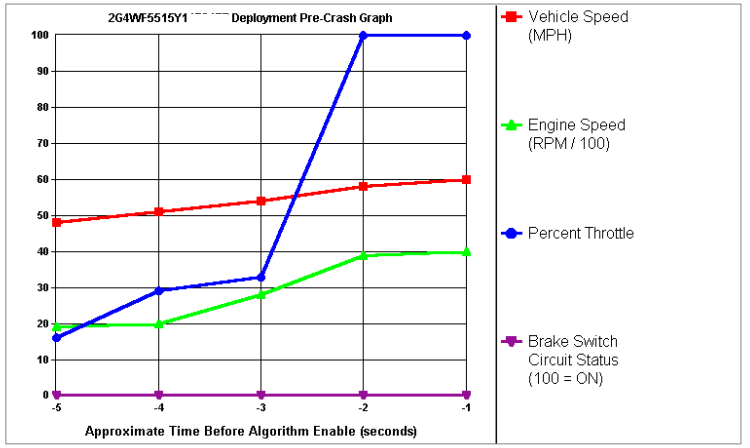

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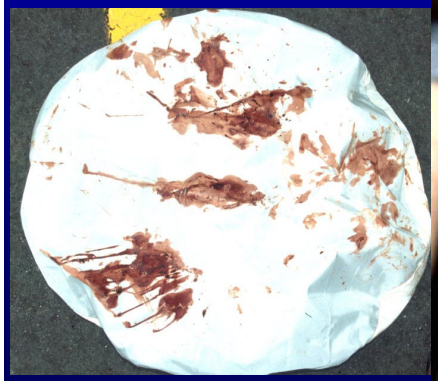

No evidence of belt use

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Driver Injuries

Medical images, injury photographs and diagrams removed

- 40 year-old male driver; 6’ 0”; 210 lb
- 3-point belt not worn, frontal-impact airbag deployed
- AIS-3 facial fractures from head contact with upper instrument panel
- AIS-3 chest injury from crash forces
- no brain, neck or abdominal injuries
- disabling lower-extremity fractures

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Patterns of Injury in Frontal Crashes

- With only airbag (angular impacts)
  - Head, face, and thorax injuries are common from contact with A-pillar, IP, windshield from "skipping off, rolling off, or missing the airbag"
  - Upper and lower extremity injuries still common

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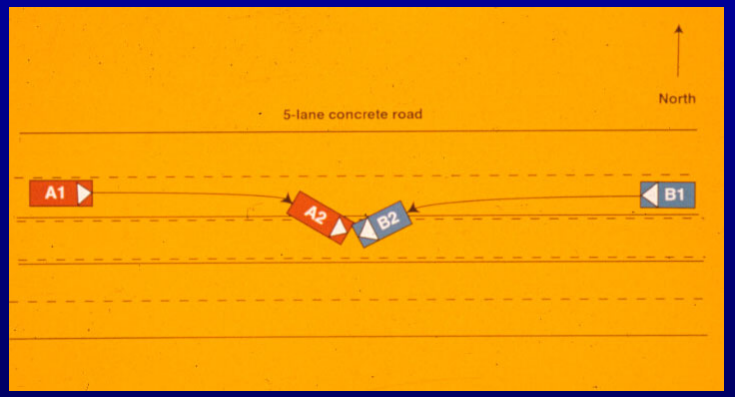

Case Vehicle (A): 1996 Ford Crown Victoria (in red)

Vehicle (B): 1990 Toyota Celica

V2 traveling in wrong lane, both drivers swerve to miss each other and hit headon

Daylight, clear, dry concrete roadway

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24-mph EBS

CDC = 12-FYEW-2

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Medical images, injury photographs and diagrams removed

- 72 year-old male driver; 5' 11"; 159 lb
- 3-point belt not worn, airbag deployed
- skipped off, rolled off, or missed airbag
- AIS-3 neck injury from head contact with WS/header
- AIS-3 hip fracture from knee contact with knee bolster

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Patterns of Injury in Frontal Crashes

- **With only airbag**
  - **Head, face, and thorax injuries are common from contact with A-pillar, IP, windshield from "missing the airbag."**
  - **Lower extremity injuries still common**
  - **Airbag-induced injuries more likely, especially to OOP (out-of-position) occupants, including contusions, abrasions, upper extremity fractures, and brain, neck, and chest injuries**

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Examples of Airbag-Induced Skin Abrasions

Medical images, injury photographs and diagrams removed

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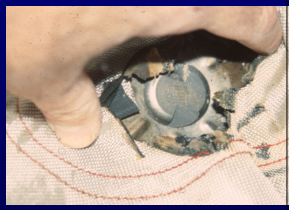
Full-thickness burn from direct contact with the inflator canister due to cargo loading from behind

Medical images, injury photographs and diagrams removed



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Skin Burns from Exposure to Hot Airbag Gases

Medical images, injury photographs and diagrams removed

Medical images, injury photographs and diagrams removed

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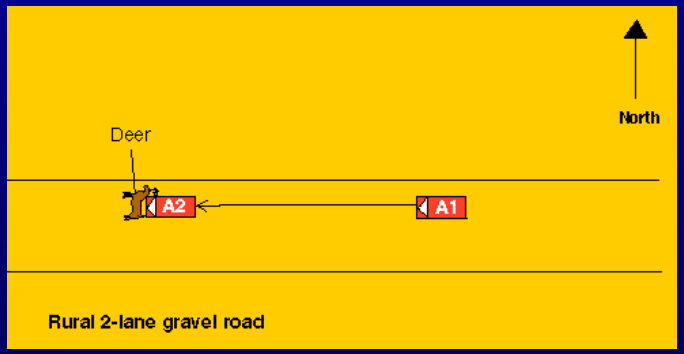
Airbag-Induced Forearm Fractures



Case Vehicle (A): 1998 Ford Windstar (in red)
Case vehicle strikes deer in roadway
Dark, cloudy, dry gravel roadway

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Airbag-Induced Forearm Fractures

1-2 mph ΔV

CDC = 12-FDEW-1

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Airbag-Induced Forearm Fractures

Medical images, injury photographs and diagrams removed

Displaced, comminuted right distal radius fracture and right ulnar styloid process fracture from loading by inflating airbag

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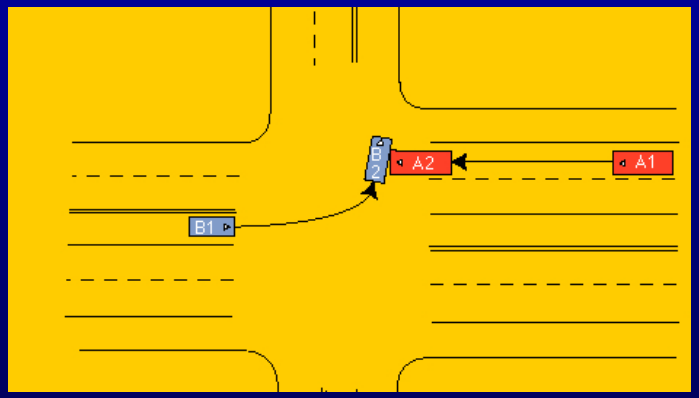
Airbag-Induced Forearm Fractures



Case Vehicle (A): 1997 Ford Super Club Wagon (in red)
Vehicle (B): 1991 Buick LeSabre
Vehicle (B) turns left, case vehicle strikes Vehicle (B) in right side
Daylight, rain, wet asphalt roadway

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Airbag-Induced Forearm Fractures

11-mph ΔV
CDC = 12-FDEW-2

22-mph ΔV
CDC = 02-RPAW-3

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Airbag-Induced Forearm Fractures

Medical images, injury photographs and diagrams removed

Hand print visible on AB module cover
Severely comminuted radius and ulna fractures

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OOP Child Airbag-Induced Brain Injury

- **1997 Ford F-150 pickup**
- **Low speed, pre-impact braking**
- **Unbelted 9-year old RF passenger**
- **AIS-5 brain injury from airbag inflation and/or airbag fling into WS and WS header**

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OOP Child Airbag-Induced Fatality

- 1998 Pontiac Grand Prix
- pre-impact braking, 18 mph ΔV
- unbelted 7 year-old RF passenger
- AIS-2 facial fracture from contact with AB cover
- AIS-3 skull fracture from contact with WS and WS header (airbag fling)
- AIS-4 brain injuries from contact with WS and WS header (airbag fling)

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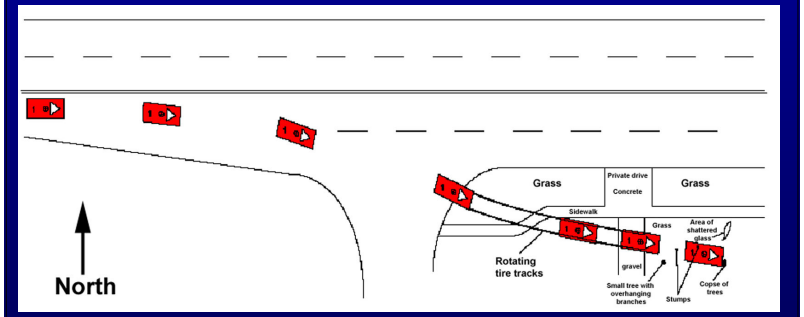
Depowered Airbag-Induced FATAL Head, Neck, and Chest Injuries



Low-speed, narrow frontal impact of 1999 Ford Taurus with a tree

Unbelted, older male drive probably OOP

Fatally injured

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3 - 8 mph ΔV

CDC = 12-FZEN-1

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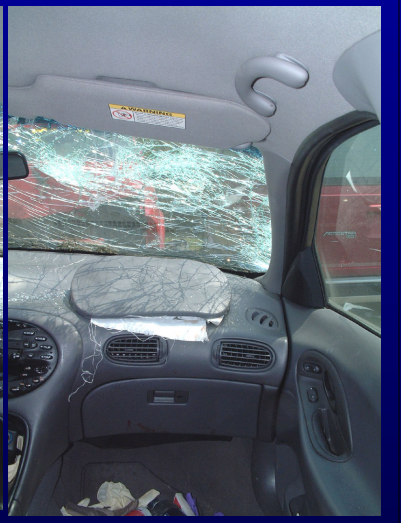

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Medical images, injury photographs and diagrams removed

62 year-old male driver, 3-point belt not worn, airbag deployed
probably OOP and against SW at AB deployment
AIS-3 chest injury from airbag inflation energy
AIS-4 skull fracture from head contact with B-pillar (airbag fling)
AIS-5 brain injury from head contact with B-pillar and/or airbag inflation energy

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Patterns of Injury in Frontal Crashes

- **With Seatbelt + Airbag**
  - Minimal head, chest, neck, abdomen injuries
  - Rib, sternum, and clavicle fractures still possible from belt loading, especially as severity increases and/or occupant age increases
  - Lower extremity (ankle/foot & hip) fractures are still common
  - Forearm, wrist, and hand fractures also occur, some airbag induced

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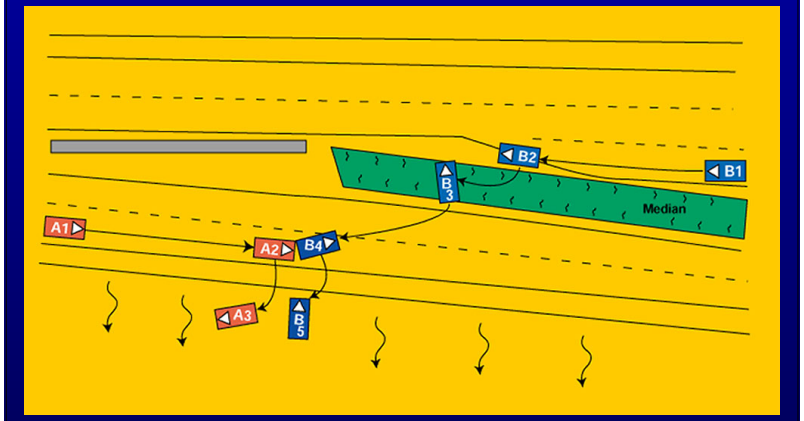

Case Vehicle (A): 1998 Saturn SW1 (in red)

Vehicle (B): 1998 Ford Mustang

Vehicle (B) loses control, rotates and crosses median,striking case vehicle rear-to-front

Dark, rain, wet asphalt roadway

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40-mph ΔV

CDC = 12-FDEW-4

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22 cm driver toepan intrusion

13 cm driver I.P. intrusion

Steering-wheel rim deformed

8 cm RF toepan intrusion

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Medical images, injury photographs and diagrams removed

- **36 year-old male driver; 6’ 7”; 252 lb**
- **3-point belt worn, airbag deployed**
- **sustained all AIS-1 (minor) injuries**

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Medical images, injury photographs and diagrams removed

- 31 year-old female RF passenger; 5’ 6”; 135 lb
- 3-point belt worn, airbag deployed
- AIS-2 chest injury from belt loading
- No serious head, neck, or abdominal injuries
- No upper or lower extremity fractures

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Case Vehicle (A): 1997 Ford Escort, 4-door station wagon (in red)
Vehicle (B): 1998 Pontiac Grand Am
Vehicle (A) attempted wide left turn and struck vehicle (B) headon
Daylight, clear, dry asphalt roadway

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46-mph ΔV

CDC = 12-FYEW-5

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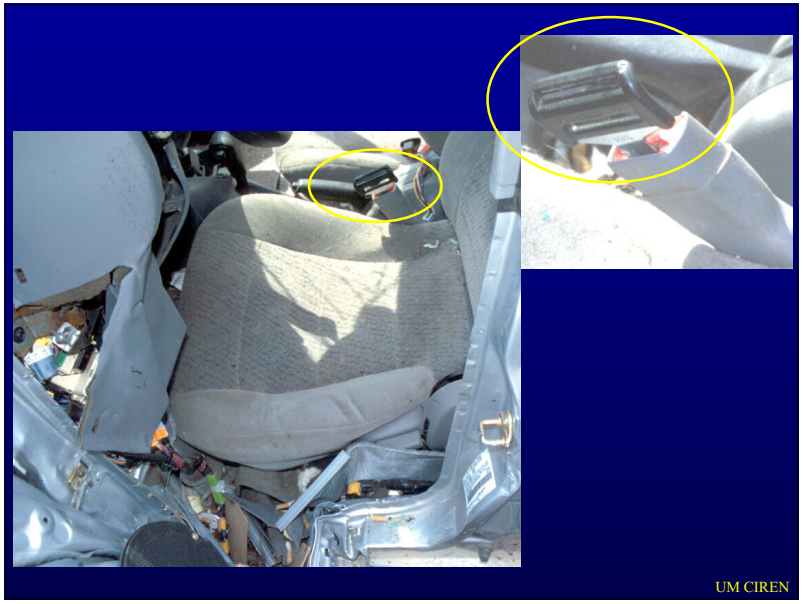

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Medical images, injury photographs and diagrams removed

- **61 year-old female driver; 5’ 6”; 170 lb**
- **3-point belt worn, steering-wheel airbag deployed**
- **AIS-3 chest and pelvic injuries from belt loading**
- **No head, brain, neck or abdominal injuries**
- **AIS-2 lower extremity fractures still present**

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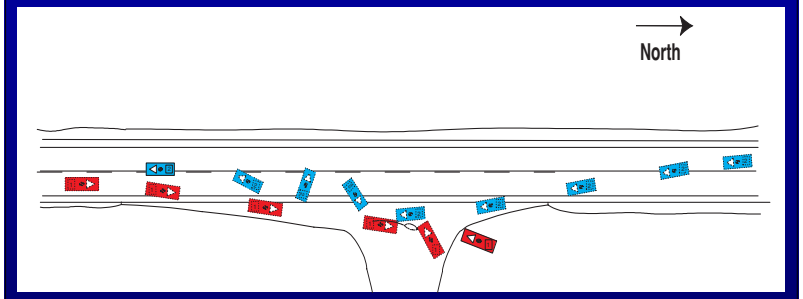

Case Vehicle (A): 1995 Ford F-150, extended cab pickup (in red)

Vehicle (B): 1996 Dodge Caravan

V2 crossed centerline, driver of case vehicle steered right to avoid a collision but struck V2 on right shoulder

Daylight, rain, wet asphalt roadway

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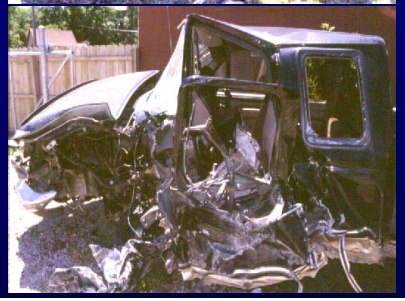

21-mph + ΔV

CDC = 12-FLEW-2

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Left wheel base reduced 57 cm

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Medical images, injury photographs and diagrams removed

- 37 year-old male driver; 5’ 10”; 230 lb
- 3-point belt worn, airbag deployed
- AIS-2 brain injury from crash forces
- No chest, abdomen, or pelvic injuries
- AIS-3 lower extremity fractures still present

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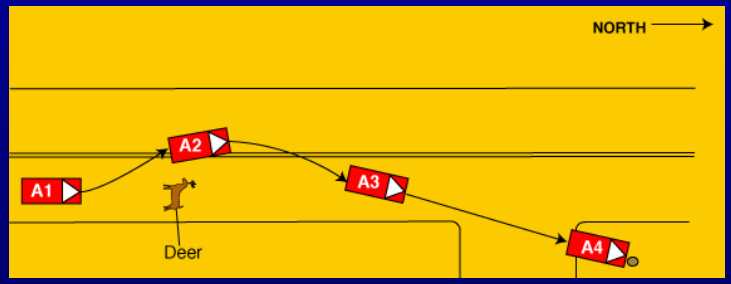
Crash Scenario



- Case Vehicle (A): 1997 Ford Windstar (in red)
- Driver swerved to miss a deer, lost control and departed right-side of roadway striking a small tree
- Driver braked with right foot

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Case Vehicle - 1997 Ford Windstar

CDC: 12-FZEN-3

24-mph delta V

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Driver was wearing the belt restraint and the airbag deployed

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No intrusions in the driver area

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Medical images, injury photographs and diagrams removed

Driver:

- 17 year-old male; 5’ 9’ 166 lb
- 3-point belt worn
- frontal-impact airbag deployed
- no intrusions
- pre-impact braking
- AIS-3 pelvic injury from axial loading through foot contact with brake pedal

Medical images, injury photographs and diagrams removed

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Changing Patterns of Injury in Frontal Crashes by Restraint Conditions

- Injury patterns and body regions change
  - As restraint type and use changes
  - As occupant injury tolerance changes
- Lower extremity injuries, especially those to the Knee-Thigh-Hip complex (KTH) are relatively constant across all restraint and occupant tolerance variations

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KTH Fractures in U of M CIREN Database

(preliminary analysis as of 6/2002)

- Frontal and offset-frontal impacts only
- 85 case occupants with KTH fractures/dislocations
  - 76 drivers, 9 RF passengers
  - 43 men, 42 women
- 185 KTH injuries
  - 106 Hip/Pelvis injuries, 46 femur injuries, and 30 knee injuries
  - Injuries relatively equally distributed across age, gender, and stature

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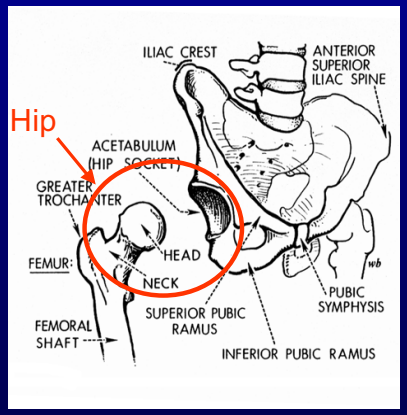
Definition of Hip



For this study, the hip is defined as the acetabulum, femoral head, and femoral neck

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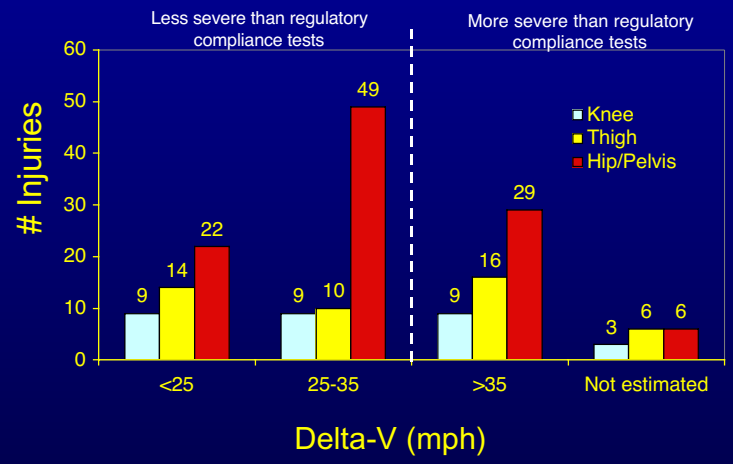
Distribution of Injuries by Delta-V (N=185)



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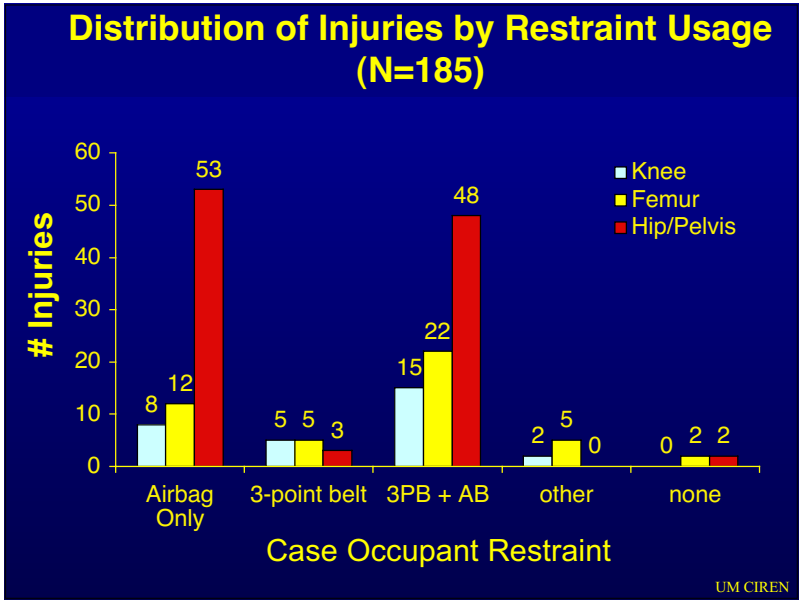
Distribution of Injuries by Restraint Usage (N=185)
Injuries
60
50
40
30
20
10
0
8
12
53
5
5
3
15
22
48
2
5
0
0
2
2
Knee
Femur
Hip/Pelvis
Airbag Only
3-point belt
3PB + AB
other
none
Case Occupant Restraint
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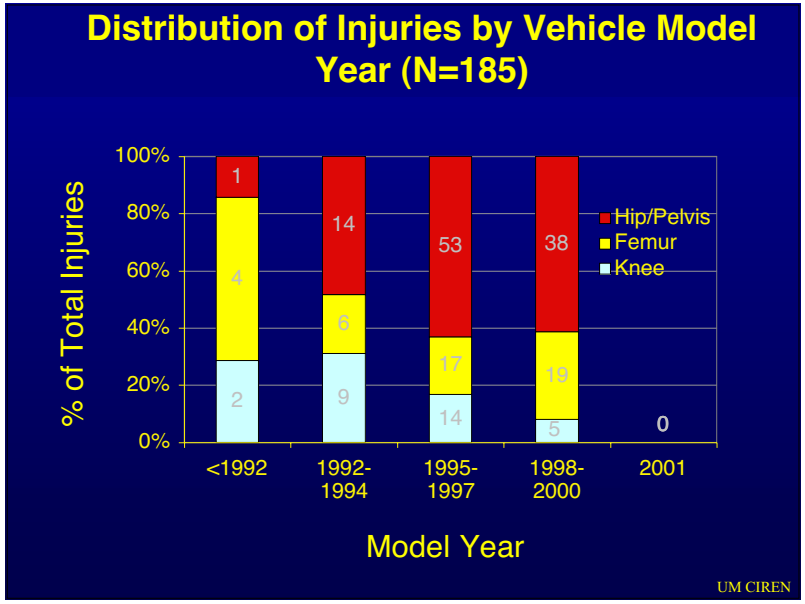
Distribution of Injuries by Vehicle Model Year (N=185)
% of Total Injuries
100%
80%
60%
40%
20%
0%
1
4
2
14
6
9
53
17
14
38
19
5
0
Hip/Pelvis
Femur
Knee
<1992
1992-1994
1995-1997
1998-2000
2001
Model Year
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Benefits of the CIREN Project

- Excellent tool to augment the use of NASS data for a variety of biomechanical analysis
- Only major crash database with detailed medical information and imagery
- Validate experimental procedures and methodologies in biomechanical research

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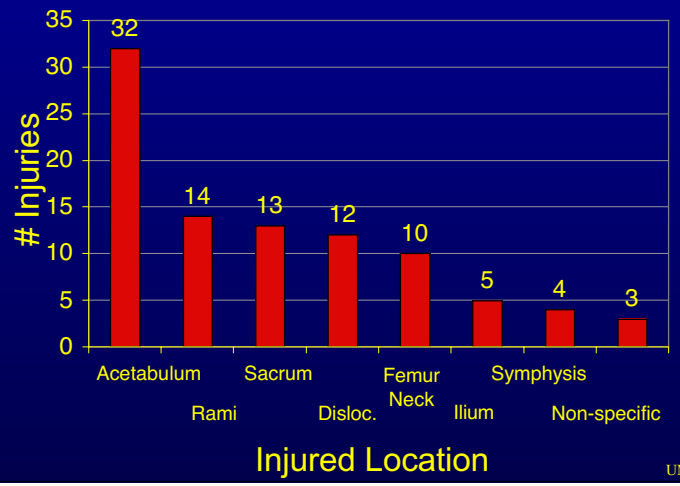
Distribution of Hip/Pelvis Injuries in U of M CIREN



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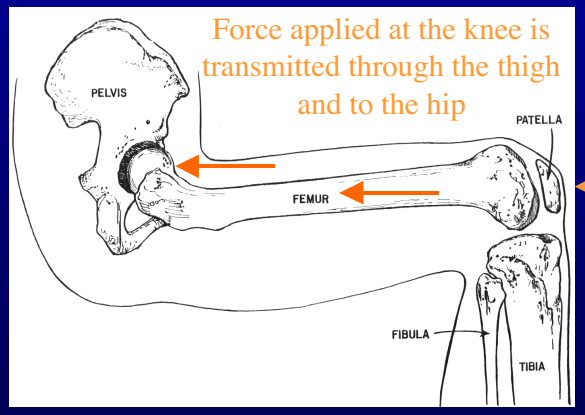
General Injury Scenario



Bolster-to-knee impact force

Body motion

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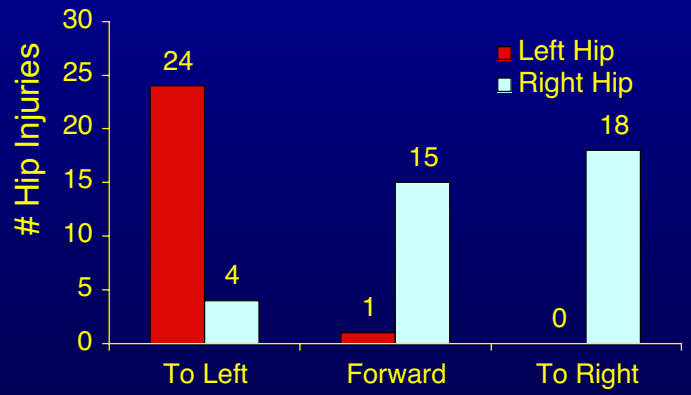
Distribution of hip injuries by direction of occupant motion (N=106)



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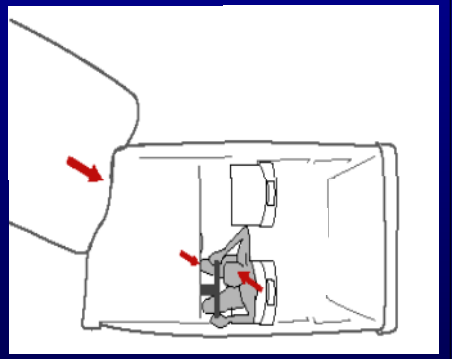
Hypothesized Effects of Occupant Kinematics and Hip Angle on Hip-Injury Tolerance

Occupant motion results in:

- adduction and/or flexion of the hip,
- asymmetric loading of one KTH, or
- both of the above



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Observations from CIREN database

- UM CIREN cases include a relatively high incidence of hip fractures & dislocations, and relatively lower incidence of knee fractures and ligamentous knee injuries. Most hip injuries were to the acetabulum, in particular, the posterior acetabular wall.
- These injuries have occurred to belt-restrained front-seat occupants seated in FMVSS 208-compliant vehicles involved in frontal crashes with impact severities of 25 to 35 mph and lower.
- The number of hip/pelvis injuries is increasing relative to the number of knee and femur injuries in newer model vehicles.
- Hip Fx/Dislocations tend to occur when the conditions of impact induce body movement that results in a change in the orientation of the leg on the injured side.

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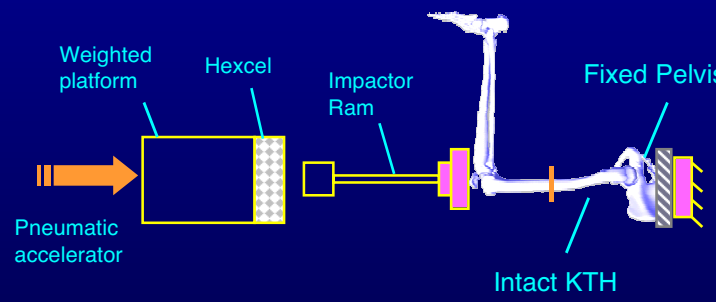
Hip Tolerance Testing

Schematic of test setup



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Isolated Pelvis Test Results

Typical fractures

Fracture from CIREN

Medical images, injury photographs and diagrams removed

Fracture from testing

Medical images, injury photographs and diagrams removed

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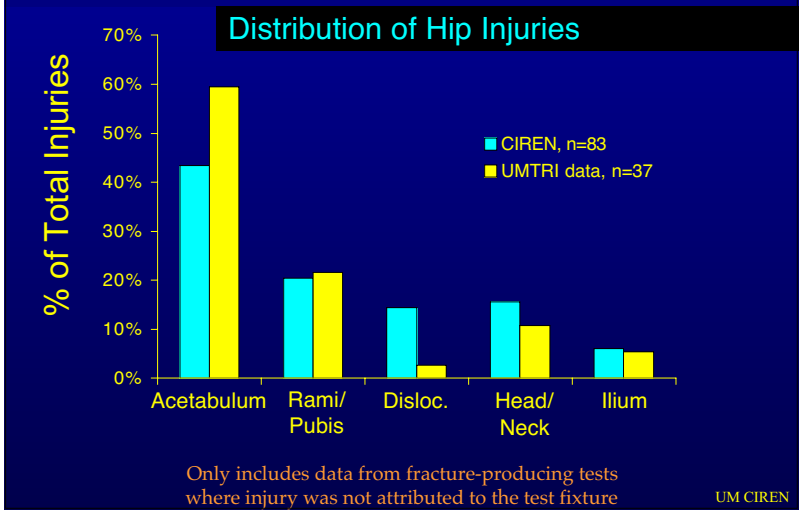
Isolated Pelvis Test Results



Only includes data from fracture-producing tests where injury was not attributed to the test fixture

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Hip Injuries

Preliminary overview

Detailed analysis, findings, and conclusions to be presented at 2002 Stapp Car Crash Conference and 2003 SAE Congress

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Thank-you for you attention!

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